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HANGING FORMWORK TECHNIQUE AS NEW INNOVATION FOR CASTING PLATES WITHOUT SCAFFOLDING

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ABSTRACT

Hanging Formwork Systems is a form of use of formwork for casting slab without using poles and quite efficiently applied in the implementation of building additions to fixed activities in the old building. Hanging formwork is a building element that functions while, so the efficiency of the material and the work is very important to reduce the cost of implementation of the work structure. The purpose of this study was to analyze the structure of the Hanging Formwork system while the purpose of this study was to review the cost-efficiency ratio formwork system hanging and conventional formwork system. This type of research is "Innovation Engineering" with the experimental method. Innovation Research Engineering with an experimental method is a study conducted by the technical problems encountered in the field, then gave birth to new innovations in engineered the settlement of the problem as problem - solving, and subsequently applied experimentation in the field that is scientifically calculated carefully and accurately, both of aspects of strength and cost aspects. This study was born spontaneously to answer any additional floors (3rd floor) in a 2-story building where owners requested to remain and act on the 2nd floor. From these results, we can conclude several things, among others: (1). The formwork system is hanging, very effectively applied to the implementation of the renovation of the building, requiring the basement still functioning, during the implementation process of construction of floors on it. (2). The system formwork hanging, more efficient in terms of execution time compared to the time of making a conventional formwork. (3). The formwork system is hanging, the cost is more economical compared to the costs of conventional formwork. (4). The cost efficiency in the implementation of hanging formwork for floor slabs measuring 4 x 4 m2, as follows: (i) The cost efficiency for the 3rd floor, amounting to 57.69%; (ii) The cost efficiency for the 4th floors, amounting to 60.23%.

KEYWORDS: Hanging Formwork, Scaffolding & Renovation

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INTRODUCTION

In the field of technology and engineering, every job challenges will drive new innovations emerge, whose sole purpose is to solve the challenges or problems that arise, but sometimes the resulting solution will be the new findings. Challenges can be derived from the potential limitations of nature and the environment, and can also be derived from the limits set by the owner of the work. As with the findings of the foundation “Cakar Ayam” system by Sudiyatmo, due to the limited carrying capacity of the soil at the location of the tower placement electricity network in Jakarta. Also finding beam girder "Sosro Bahu" system by Cokorda, due to the limited workspace in the construction of flyovers in Jakarta. And many more examples of the new findings, which was born from the work challenges facing engineering experts, which ultimately provides many benefits in the development of science and technology, and also in the completion of complex work in the field.

SOURCE OF INNOVATION

The research appears spontaneously, to answer the problem adding floors (3rd and 4th floor) in a 2-story building, which the owners ask to be able to stay and indulge in the 2nd floor. The provisions of the building owner as well as a challenge for the writers, because it resulted in no scaffolding should not be placed on the 2nd floor. The problem for the designer is the casting work of slab and beam 3rd floor, for using concrete materials.

Writers are being engineering, formulating the solution by the analytical approach, with problem solving systematic as follows:

- Materials for structural beams and slabs for 3rd floors does not allow all of the concrete material because it will require formwork equipped with scaffolding.
- Materials for structural beams and slabs for 3rd floors must meet the technical requirements of the main structure, as it will support the weight of the building above the 4th floor.
- Analysis of mechanics and statics of structural beams and slabs should be done for every floor.

Based on a systematic problem-solving, the author's designed formwork concrete floor plate without scaffolding, which later authors termed "formwork hanging".

MECHANICS ANALYSIS

Based on the results of the development of innovation to create a formwork for casting slab without scaffolding, the authors decided to use the beams on the third floor of the steel material IWF profile. This decision was based on the consideration that the bottom flange of the steel IWF, can be utilized for a footstool girder slab formwork, instead of scaffolding. In addition, IWF steel flangealso can become binding on its hanger beams, which beams the hanger, also a pedestal girder slab formwork.

Thus there are some elements that need to be analyzed formwork structure strength, among others: (1) the strength of the beam hanger, C10 profile of the steel material; the strength of the formwork girders, wood 5/10; the strength of the beam formwork, wood 4/6; and the strength of the contact formwork, material multiplex with 9 mm thick. By cascading, the analysis of the strength of the formwork elements can be summarized as follows:

Strength Analysis of the Contact Formwork

Material : Multiplex = 9 mm.

$E = 80.000$ kg/cm^2 ; Body force = 0,55 kg/m' ; Poisson ratio = 0,2

Formwork beam spacing = 50 cm ; thick concrete slab = 12 cm

Weight concrete mortar = (0,12 x 0,5) x 2500 = 150 kg/m'

Total dead load (q_D) = 0,55 + 150 = 150,55 kg/m'

Live load (q_L) = 0,5 x 0,5 x 200 = 50 kg/m'

Ultimate load (q_{ult}) = 1,2 q_D + 1,6 q_L = 260,66 kg/m'

Then : M_{max} = ½ q_{ult}.L = 6 kg.m' = 600 kg.cm'.

Control analysis of Contact Formwork

- **Section Stress Control**

w_x = 1/6 b.h^2 = 1/6 (122).(0,9)^2 = 16,47 cm^3.

$$\sigma = \frac{M_{\max}}{w_x} = \frac{600}{16,47} = 36,43 kg/cm^2 < \sigma_{all} = 75 \text{ kg/cm}^2 \text{ (safe)}$$

- **Deflection Control**

I_x = 1/12 b.h^3 = 1/12 (122).(0.9)^3 = 7,41 cm^4.

Deflection allowed = $\delta_{all} = \frac{L}{240} = \frac{50}{240} = 0,21 cm$

Deflection occurs = $\delta = \frac{5}{384} q_{ult} x \frac{L^4}{(E.I_x)} = 0,19 cm < \delta_{all}$ (safe)

Strength Analysis of the Beam Formwork

Material : Wood beams, Class III, Dimension 4x6 cm

E = 80.000 kg/cm^2 ; Specific gravity = 750 kg/m^3 ; Poisson ratio = 0,2

Body force = 0,04 x 0,06 x 1,0 x 750 = 1,80 kg/m'.

Formwork beam spacing = 50 cm ; thick concrete slab = 12 cm

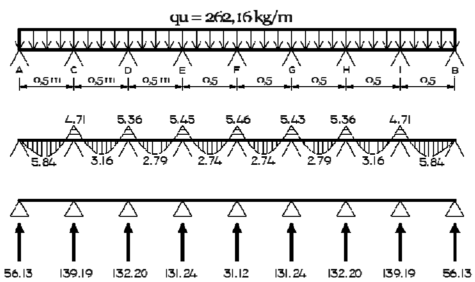
Weight concrete mortar = (0,12 x 0,5) x 2500 = 150 kg/m'

Total dead load (q_D) = 1,80 + 150 = 151,80 kg/m^1.

Live load (q_L) = 0,5 x 0,5 x 200 = 50 kg/m^1.

Ultimate load (q_{ult}) = 1,2 q_D + 1,6 q_L = 262,16 kg/m^1.

By modeling the structure, can be analyzed by SAP in 2000 as follows:



From analysis with SAP in 2000, generated:

M_{max} = 5,84 = 6 kg.m' = 600 kg.cm'.

V_{max} = 139,19 = 140 kg.

Control Analysis of Formwork Beam

- **Section Stress Control**

  w_x = 1/6 b.h^2 = 1/6 (4).(6)^2 = 24 cm^3.

  $$\sigma = \frac{M_{\max}}{w_x} = \frac{600}{24} = 25 kg/cm^2 < \sigma_{all} = 75 \text{ kg/cm}^2 \text{ (safe)}$$

- **Deflection Control**

  I_x = 1/12 b.h^3 = 1/12 (4).(6)^3 = 72 cm^4.

  Deflection allowed = $\delta_{all} = \frac{L}{240} = \frac{50}{240} = 0{,}21 cm$

  Deflection accurs = $\delta = \frac{5}{384} q_{ult} x \frac{L^4}{(E.I_x)} = 0{,}04 cm < \delta_{all}$ (safe)

Strength Analysis of the Girder Formwork

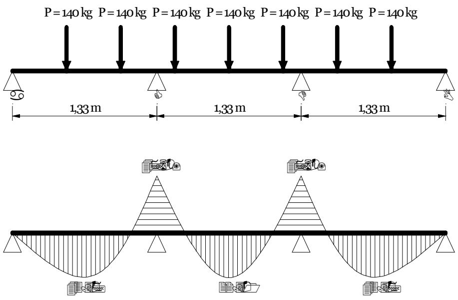
Material : Wood beam, Class III, Dimension 5x10 cm

E = 80.000 kg/cm^2 ; Specific gravity = 750 kg/m^3 ; Poisson ratio = 0,2

Body force = 0,01 x 0,10 x 1,0 x 750 = 3,75 kg/m^1.

Formwork girder spacing = 1,33 m

Point load due to the reaction of the formwork beam = P = V_{max} = 140 kg



From analysis with SAP in 2000, generated:

M_{max} = 47,69 = 50 kg.m'

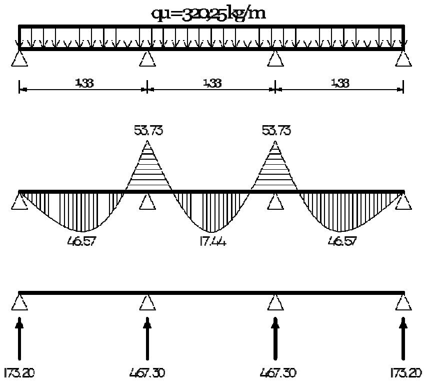
If the maximum moment as a result of the loads on the girder elements used as the load evenly.

Then load equivalent = $q_{eq} = \frac{8.M_{\max}}{L^2} = \frac{8x50}{(1{,}33)^2} = 255 kg/cm'$

Total deal load (q_D) = 3,75 + 255 = 228,75 kg/m'.

Ultimate load (q_{ult}) = 1,4 q_D = 320,25 kg/m'.

By modeling the structure, can be analyzed by SAP in 2000 as follows:



From analysis with SAP in 2000, generated:

M_{max} = 53,73 = 55 kg.m' = 5500 kg.cm'.

V_{max} = 467,30 = 470 kg.

Control Analysis of Formwork Girder

- **Section Stress Control**

w_x = 1/6 b.h^2 = 1/6 (5).$(10)^2$ = 83,33 cm^3.

$$\sigma = \frac{M_{\max}}{w_x} = \frac{5500}{83,33} = 66 kg/cm^2 < \sigma_{izin} = 75 \text{ kg/cm}^2 \text{ (safe)}$$

- **Deflection Control**

I_x = 1/12 b.h^3 = 1/12 (5).$(10)^3$ = 416,67 cm^4.

Deflection allowed = $\delta_{all} = \frac{L}{240} = \frac{133}{240} = 0,56cm$

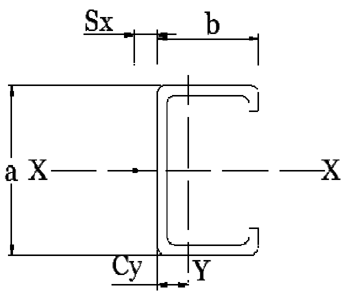
Deflection accurs = $\delta = \frac{5}{384} q_{ult} x \frac{L^4}{(E.I_x)} = 0,40cm < \delta_{all}$ (safe)

Strength Analysis of the Hanger Beam

Material : Steel Beam Profile C_{10}

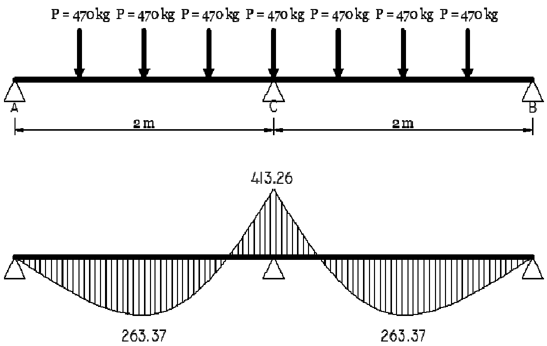
E = 200.000 MPa ; Fy = 210 Mpa Fr = 130 MPa ; Poisson ratio = 0,3

Body force of C_{10} = 5,5 kg/m'. A long stretch (L) = 2,00 m



High profile (h_t)	: 100 mm
With flange (b_f)	: 50 mm
Thick web (t_w)	: 3,2 mm
Thick flange (t_f)	: 3,2 mm
Section area (A)	: 701 mm^2
Wight profile (w)	: 55 N/m
moment of inertia-X (I_x)	: 1070000 mm^4
moment of inertia-Y (I_y)	: 245000 mm^4
Radius of inertia-X (r_x)	: 39 mm
Radius of inertia-Y (r_y)	: 18,7 mm
Moment opponent-X (S_x)	: 21300 mm^3
Momen opponent-Y (S_y)	: 7810 mm^3

Point load due to the reaction of formwork girder = P = V_{max} = 470 kg



From analysis with SAP in 2000, generated:

M_{max} = 413,26 kg.m'

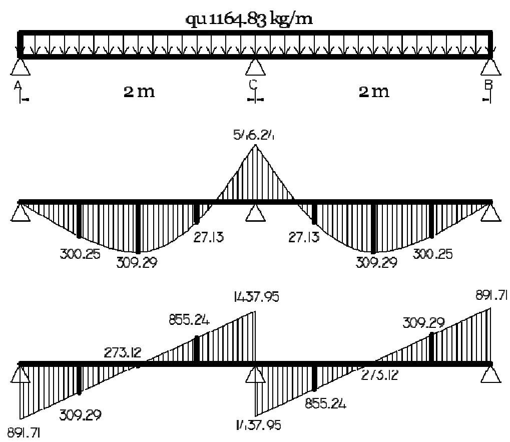
If the maximum moment as a result of the loads on the girder elements used as the load evenly.

Then load equivalent = $q_{eq} = \frac{8.M_{max}}{L^2} = \frac{8x413{,}26}{(2)^2} = 826{,}52 kg / cm^1$

Total dead load (q_D) = 5,5 + 826,52 = 832,02 kg/m^1.

Ultimate load (q_{ult}) = 1,4 q_D = 1164,83 kg/m^1.

By modeling the structure, can be analyzed by SAP in 2000 as follows:



From analysis with SAP in 2000, generated:

M_{ult} ¼ L (M_A) = 300,25 kgm

M_{ult} ½ L (M_B) = 309,29 kgm

M_{ult} ¾ L (M_C) = 300,25 kgm

M_{ult} L (M_{max}) = 310 kgm

Shear ultimate (V_u) = 1437,95 kg

Reduction of flexural strength (φ_b) = 0,90

Reduction of shear strength (φ_f) = 0,75

Control Analysis of Hanger Beam C_{10}

- **Control of Profile Flange**

The maximum slenderness requirement for compact cross-section steel profile:

$$\lambda_p = \frac{500}{\sqrt{f_y}} = \frac{500}{\sqrt{210}} = 34{,}50$$

The maximum slenderness requirement for non-compact cross-section steel profiles:

$$\lambda_r = \frac{625}{\sqrt{f_y}} = \frac{625}{\sqrt{210}} = 43{,}13$$

Slimness flange C10 profile (profile used)

$$\lambda_f = \frac{bf}{tf} = \frac{50}{3{,}2} = 15{,}63 \rightarrow \lambda_f < \lambda_p < \lambda_r \text{ (compact profile)}$$

- **Control of Profile Body**

The maximum slenderness requirement for compact cross-section steel profile:

$$\lambda_p = \frac{1680}{\sqrt{f_y}} = \frac{1680}{\sqrt{210}} = 115{,}93$$

The maximum slenderness requirement for non-compact cross-section steel profiles:

$$\lambda_r = \frac{2550}{\sqrt{f_y}} = \frac{2550}{\sqrt{210}} = 175{,}97$$

Slimness flange C10 profile (profile used)

$$\lambda_f = \frac{h}{tw} = \frac{100}{3{,}2} = 31{,}25 \rightarrow \lambda_f < \lambda_p < \lambda_r \text{ (compact profile)}$$

- **Stress Control of Profile Section**

If : M_{max} = 310 kgm = 31000 kg.cm

S_x = 21300 mm^3 = 21,30 cm^3.

Then :Stress accurs :

$$f_{act} = \frac{M_{\max}}{S_x} = \frac{31000}{21{,}30} = 1455{,}40 kg / cm^2 = 142{,}5 MPa < F_y \text{ (Safe)}$$

DISCUSSIONS

With the results of mechanical analysis above, the next writer to use "hanging formwork" at the project, which was originally a major challenge for the writer. All formwork elements which the author applied in the field is the appropriate dimensions calculated in the mechanical analysis. The application of this system on the whole successful, and casting slab and plate of the 3rd floor and 4th floor of the building, using the hanging formwork systems.

Some of the documentation of the application of hanging formwork system, as shown in the photos below:

(a): Formwork Girders above IWF Flange

(b): Formwork Beam above Girders

(c): Contact Formwork Installation

(d): Concrete Reinforcement Installation

(e): Hanging Beam Support to Formwork Girder

(f): Connecting between Hanging Beam with IWF

(g): Casting of Concrete **(h): Finishing of Surface Slab**

Figure 1: Documentation of Application 'Hanging Formwork' Systems on a Building in Makassar (2015).

For the implementation of casting slab on the 4th floor, has actually been able to use conventional formwork systems, using elements of the scaffold. But the results of a cost analysis on the system "hanging formwork" by using the IWF as the steel floor beams, it is more economical than conventional formwork system with concrete beams.

In addition, time to build of hanging formwork system shorter than the time needed to make the use of conventional formwork scaffolding. And the cost and time efficiencies of hanging formwork system on conventional formwork systems, will be even greater for jobs that getting to the top floor. The second advantage of the hanging formwork system has been analyzed by the author, will be poured on the article which would follow.

CONCLUSIONS

In particular, the above description, giving the facts as the authors' conclusion that:

- Hanging formwork system, applicable to the execution of casting slab, with formwork without scaffolding.
- Application of hanging formwork system, does not require support technology and construction equipment is complicated and expensive.

In general, from the comprehensive analysis that has been developed writers, authors can conclude some general conclusions, as follows:

- The formwork system is hanging, very effectively applied to the implementation of the renovation of the building, requiring the basement still functioning, during the implementation process of construction of floors on it.
- The system formwork hanging, more efficient in terms of execution time compared to the time of making a conventional formwork.
- The formwork system is hanging, the cost is more economical compared to the costs of conventional formwork.
- The cost efficiency in the implementation of hanging formwork for floor slabs measuring 4 x 4 m2, as follows: (1) The cost efficiency for the 3rd floor, amounting to 57.69%; (2) The cost efficiency for 4th floors, amounting to 60.23%.

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